# The Multiphase nature of FIR fine structure lines

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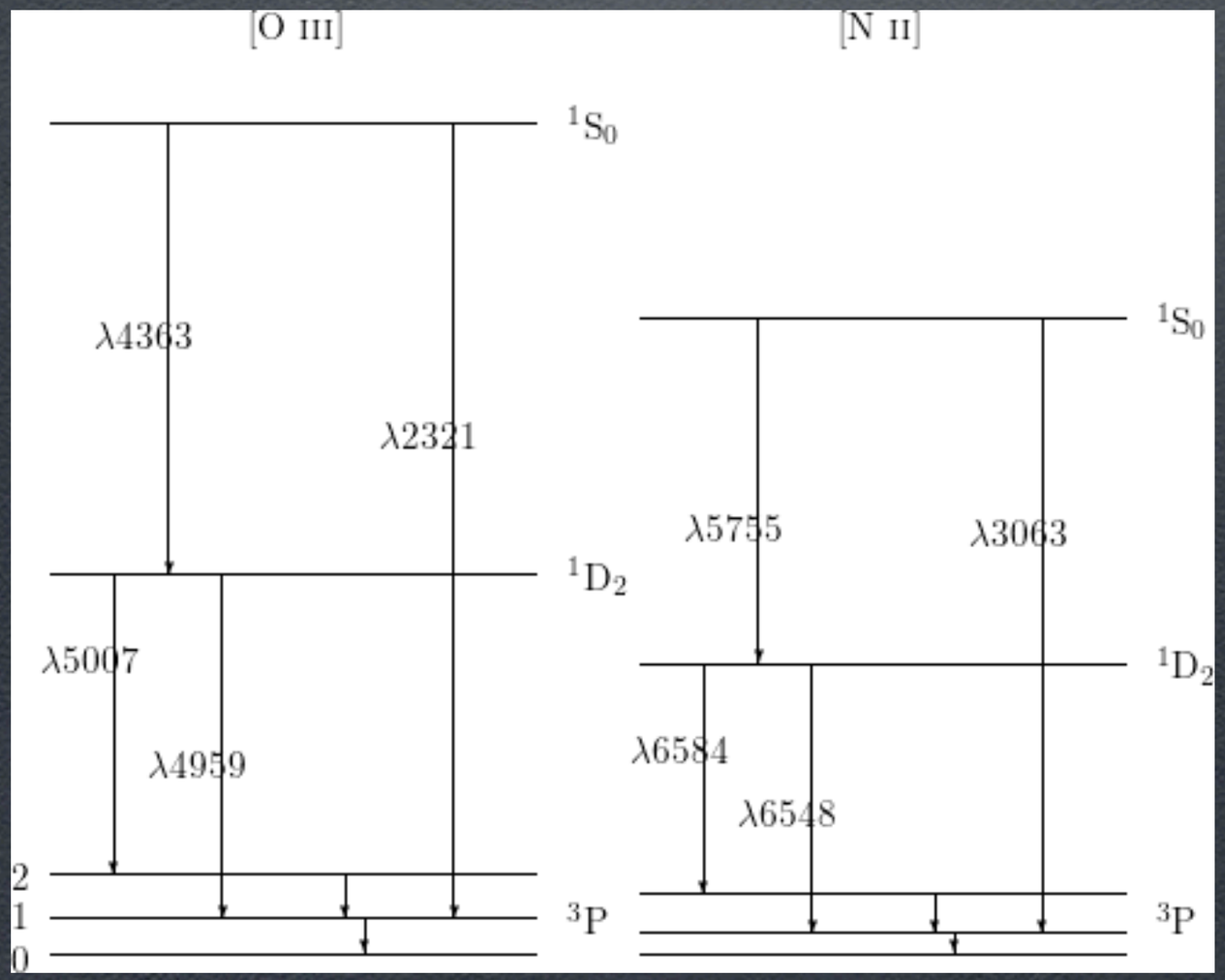
Australian Government
Australian Research Council

Australian National University

# The Fine Structure of the FIR lines

- The FIR fine structure lines are low-level transitions
- Forbidden transitions so must be collisional excited
- Low frequency means low energy means excited at low T
- Collisionally de-excited at low densities (low $n_{crit}$)




52$\mu$m
88$\mu$m

122$\mu$m
205$\mu$m

# The Fine Phases

- Ionized Medium alone
  - [OIII] 52, 88$\mu$m
  - [NII] 122, 205$\mu$m
  - [NIII] 58$\mu$m
- Ionized, Atomic, Molecular
  - [CII] 158$\mu$m
- Atomic, Molecular
  - [OI] 63, 145$\mu$m
  - [CI] 370, 610$\mu$m

# The Fine Phases

- The Line location depends on ionization potential
- Affects density sensitivity (Collision partner)
- Different heating process in each phase (ionization versus photoelectric heating)

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# Phase Separation

- What can the various FIR fine structure lines tell us about the multi-phase ISM?
- How do we separate the multiphase contribution to [CII]?
- Do we need to separate [CII]?

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Brent Groves MAPPINGS V model

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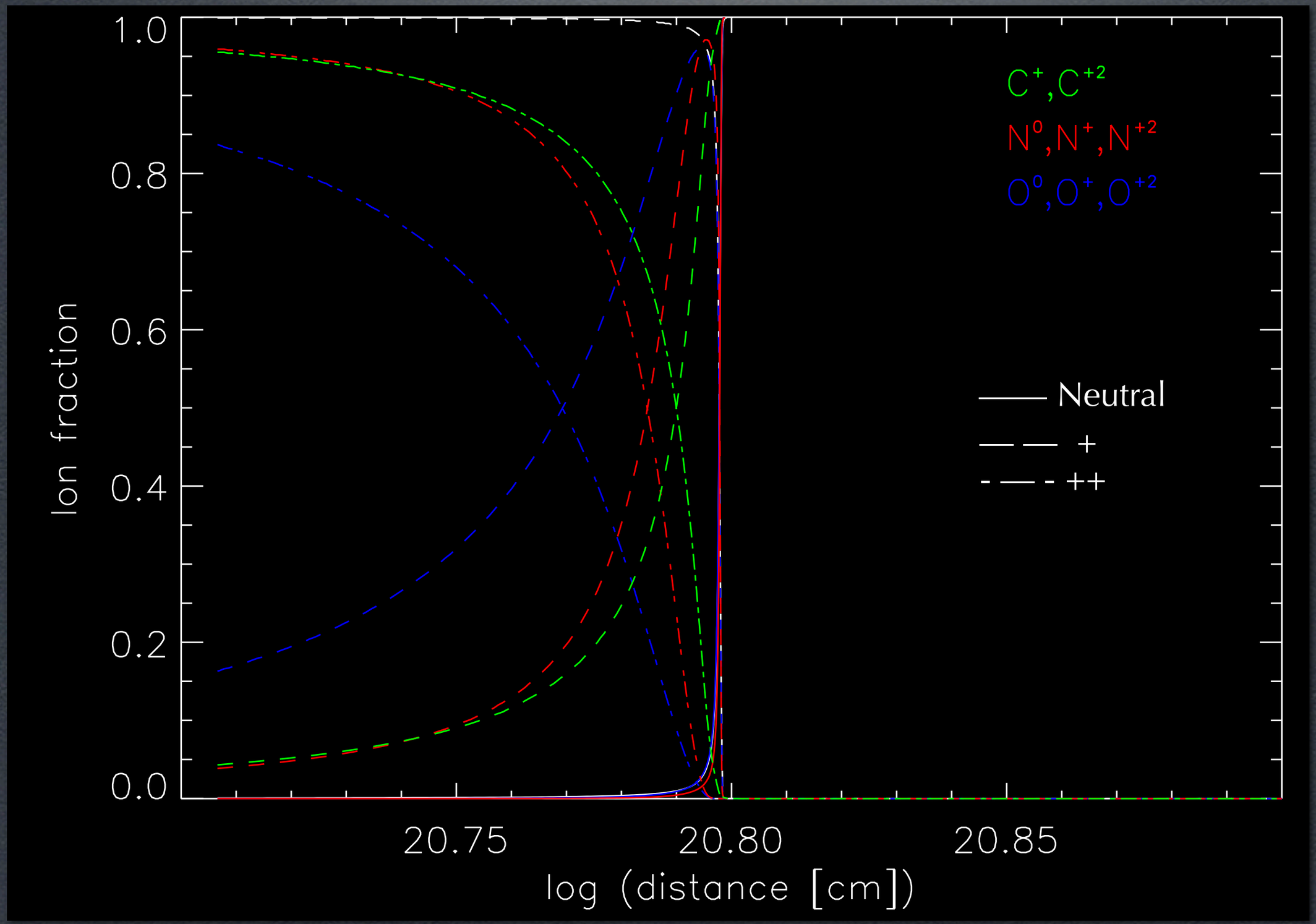


Brent Groves MAPPINGS V model

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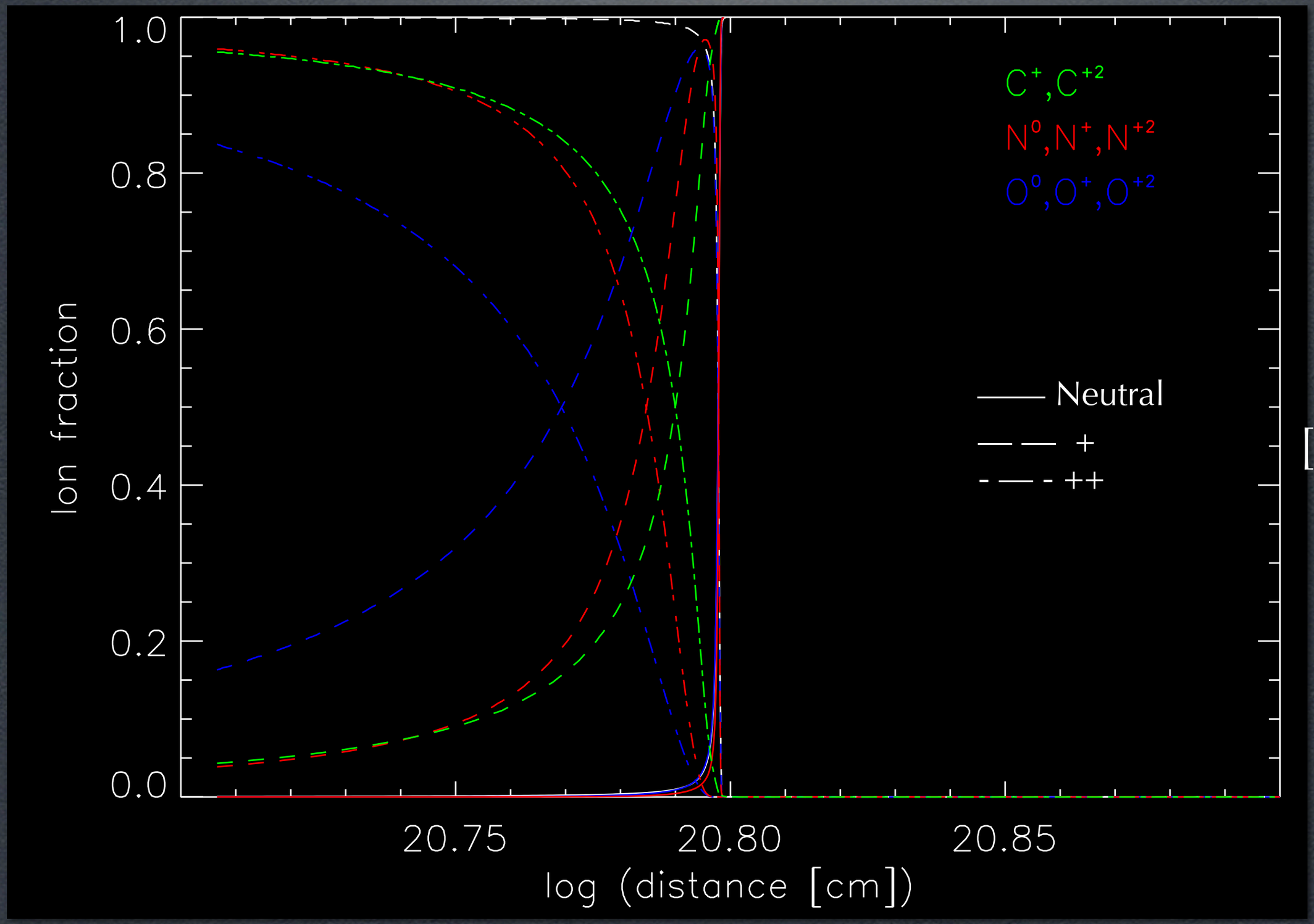


[CI] ->

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MAPPINGS V model

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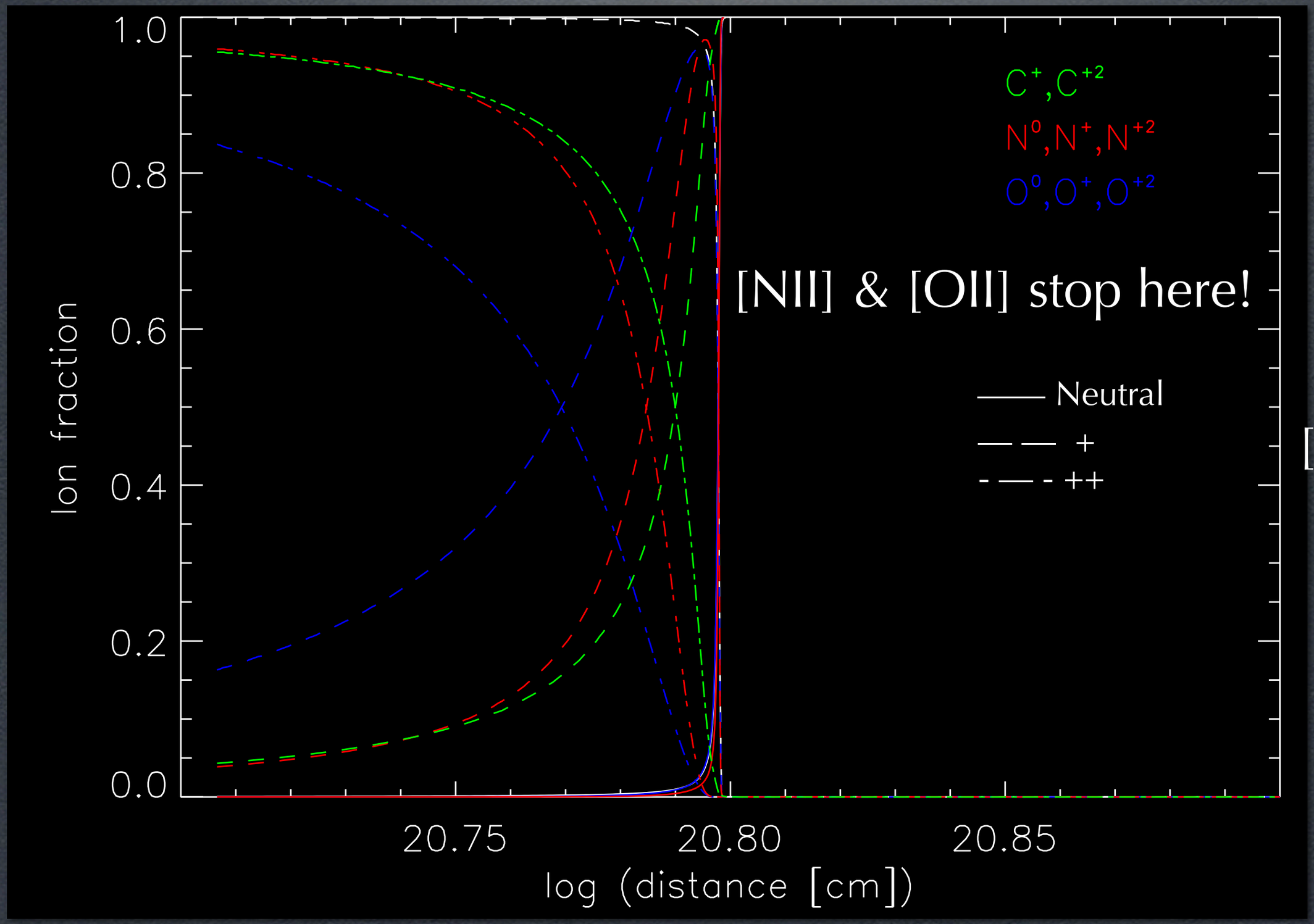

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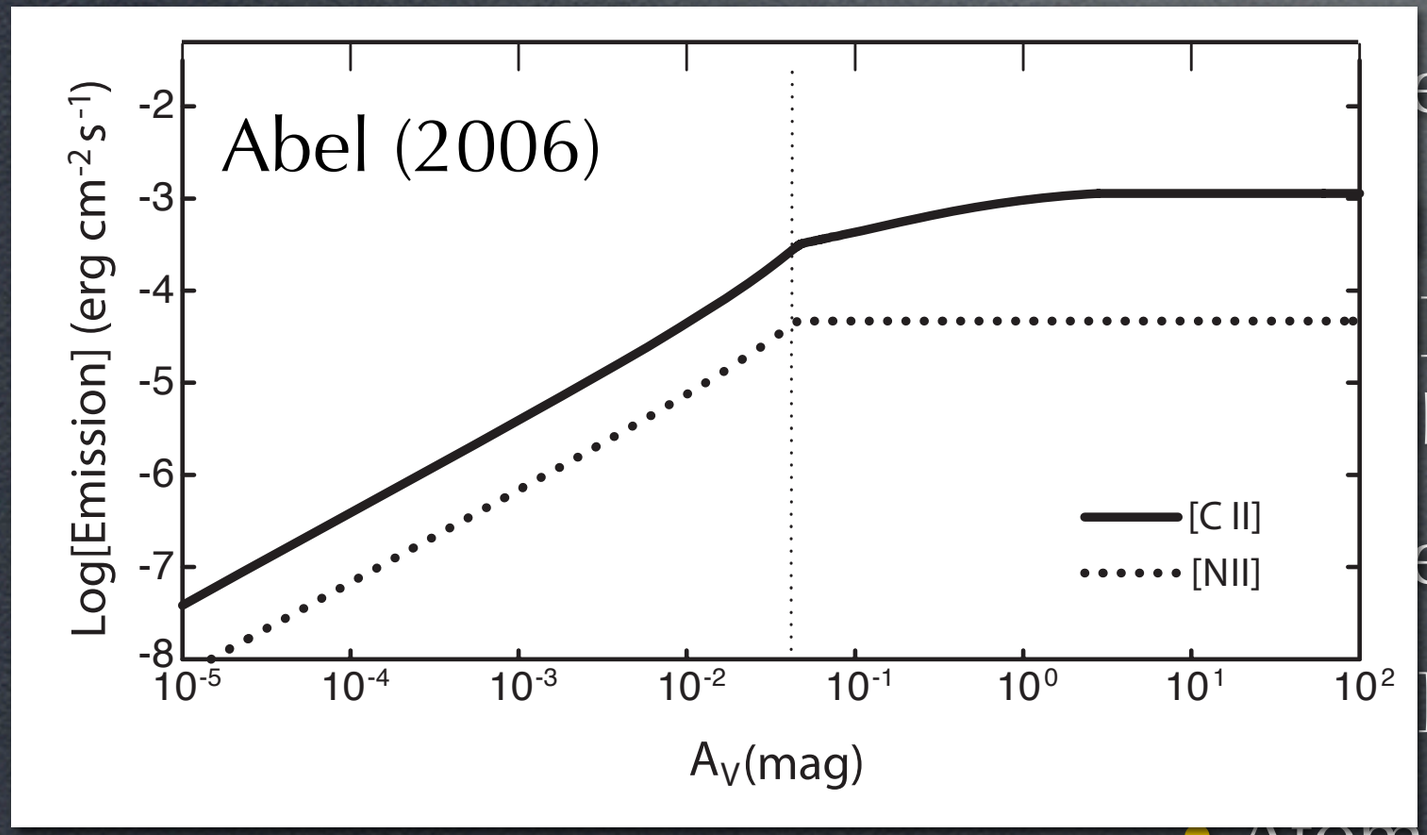


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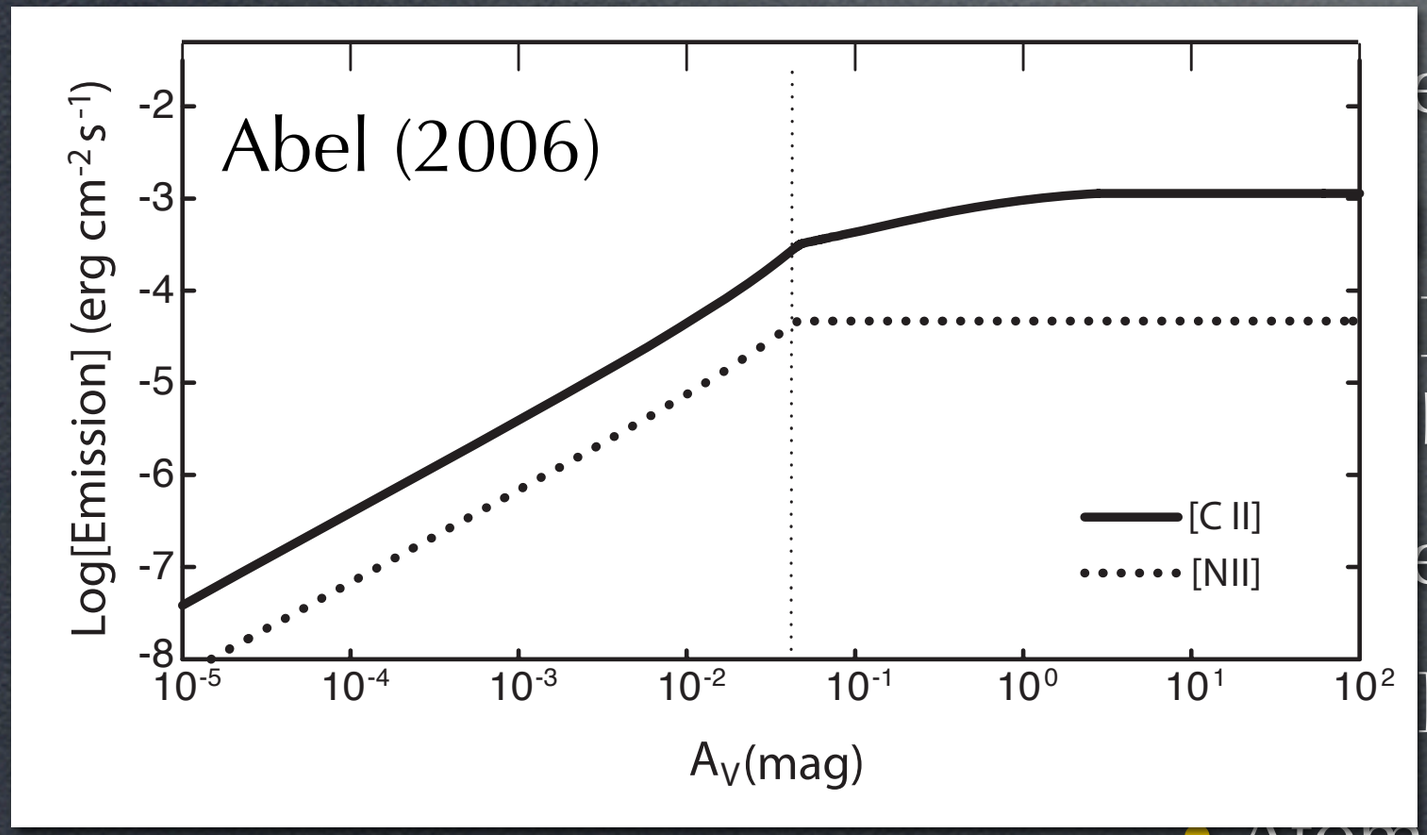


Note [SII] follows even better as $S^0$ has an IP 10.36 (below $C^0$)

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# Are we dense?

- [NII] overlaps with $[CII]_{ion}$ (as does [SII] even better…)
- But what about T and n dependence?

- Ionized phase ~8000 K >> $T_{[CII]} \sim 91$ K
- $n_{crit,e\ [CII]} \sim 50\ cm^{-3}$
  $n_{crit,e\ [NII]122} \sim 300\ cm^{-3}$
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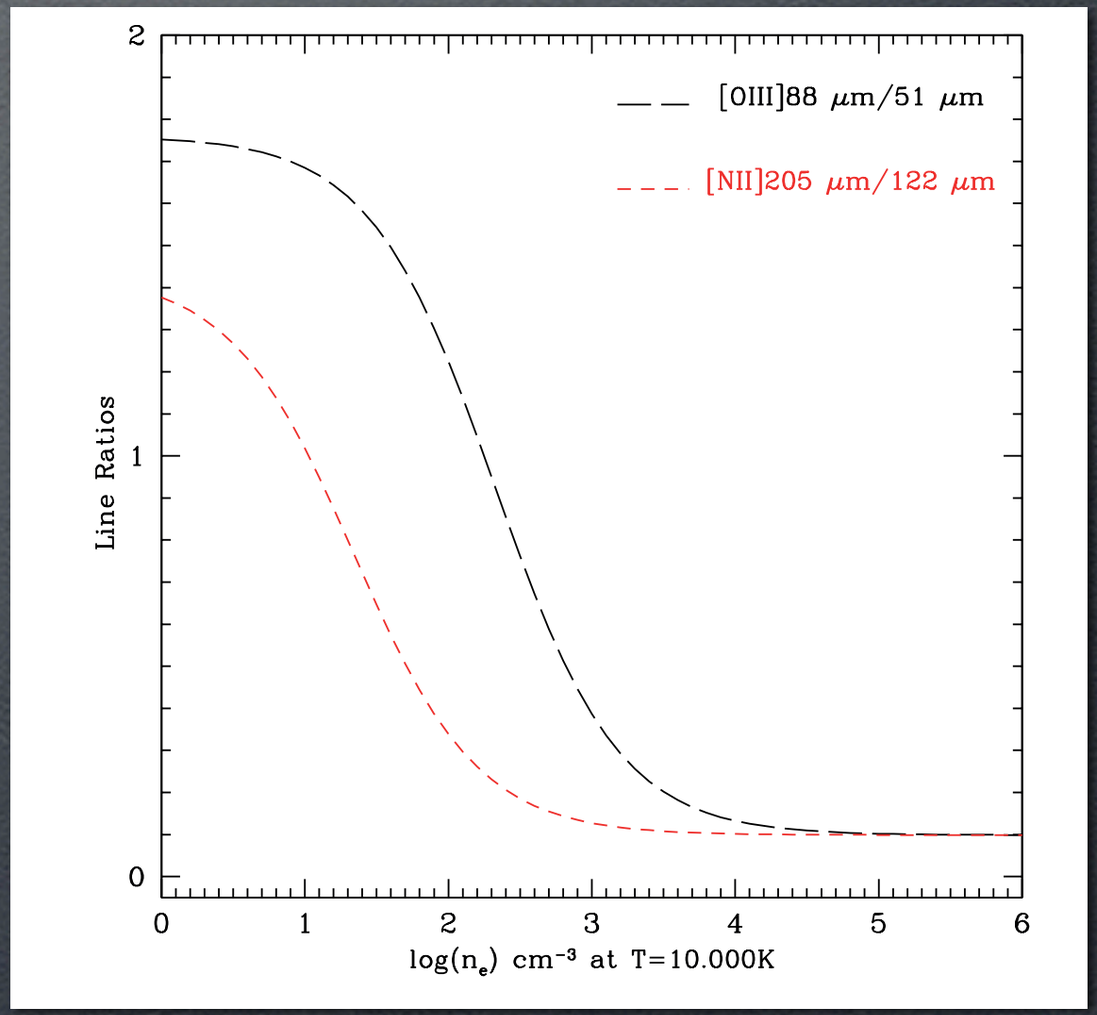

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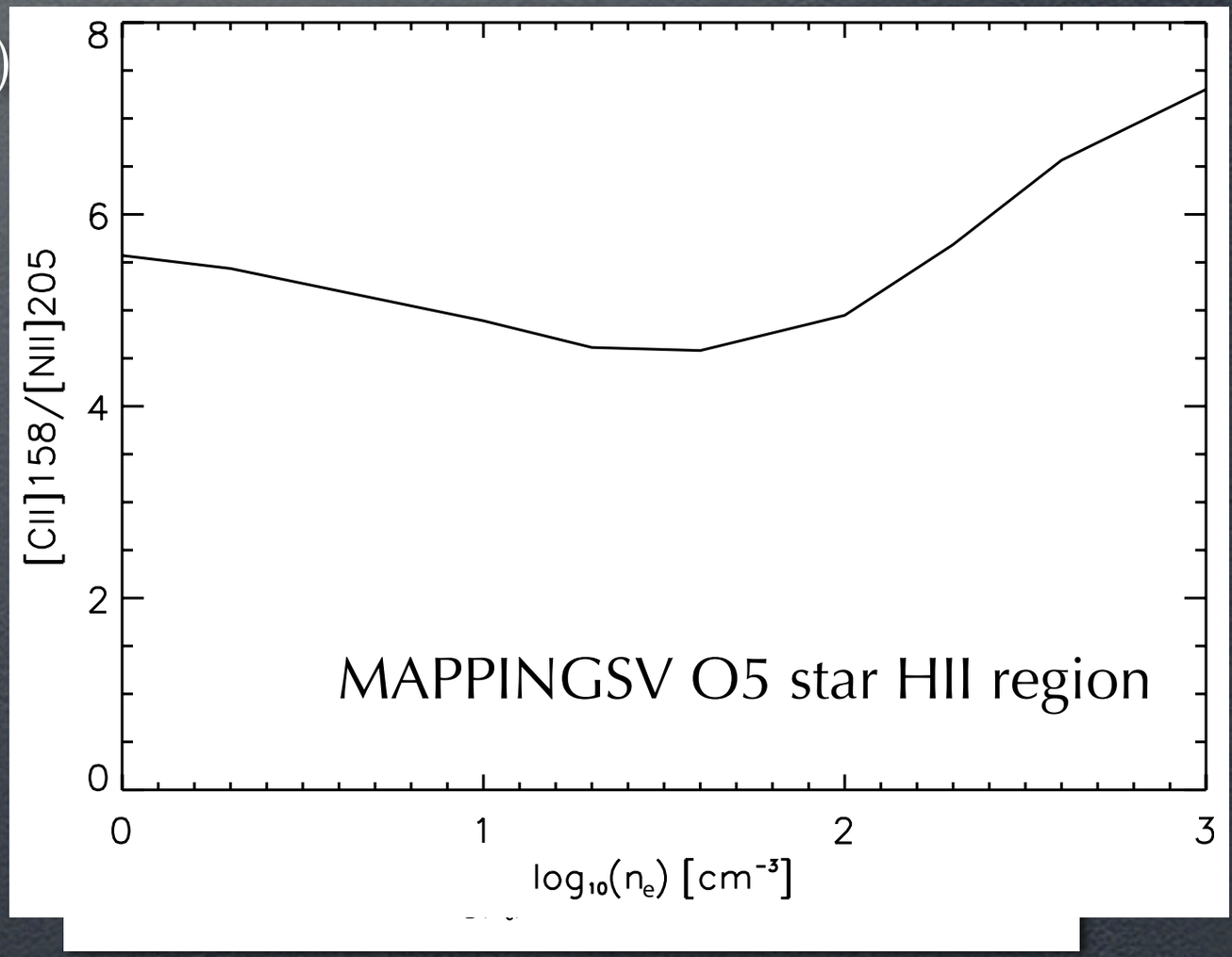
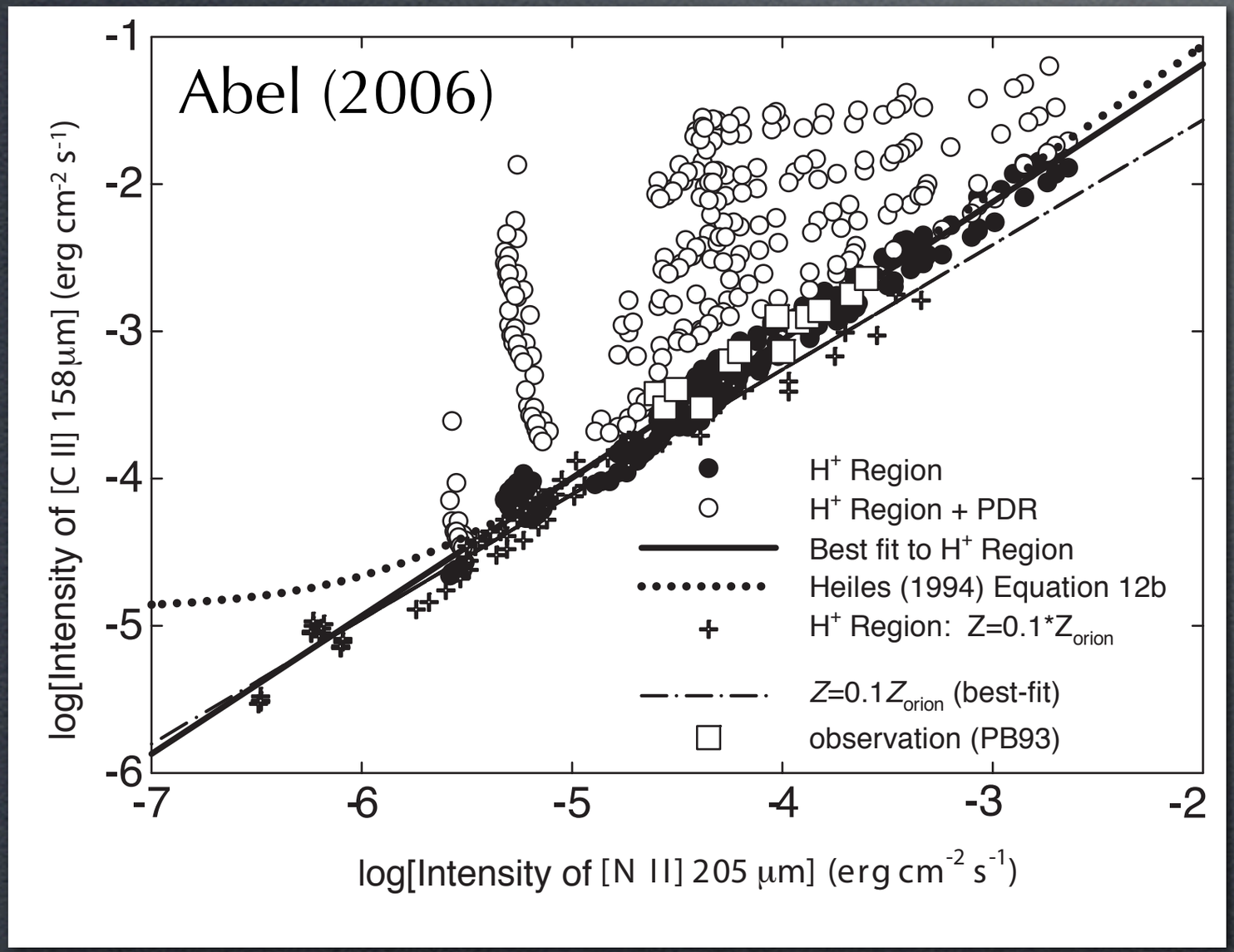


# [NII] as a tracer




- $[NII]_{205}$ will trace $[CII]_{ion}$ (uncertainty < 25% Petuchowski & Bennett 93)
- But [NII] only ~20% of $[CII]_{ion}$ (and less of full [CII])
- Also metallicity dependence?

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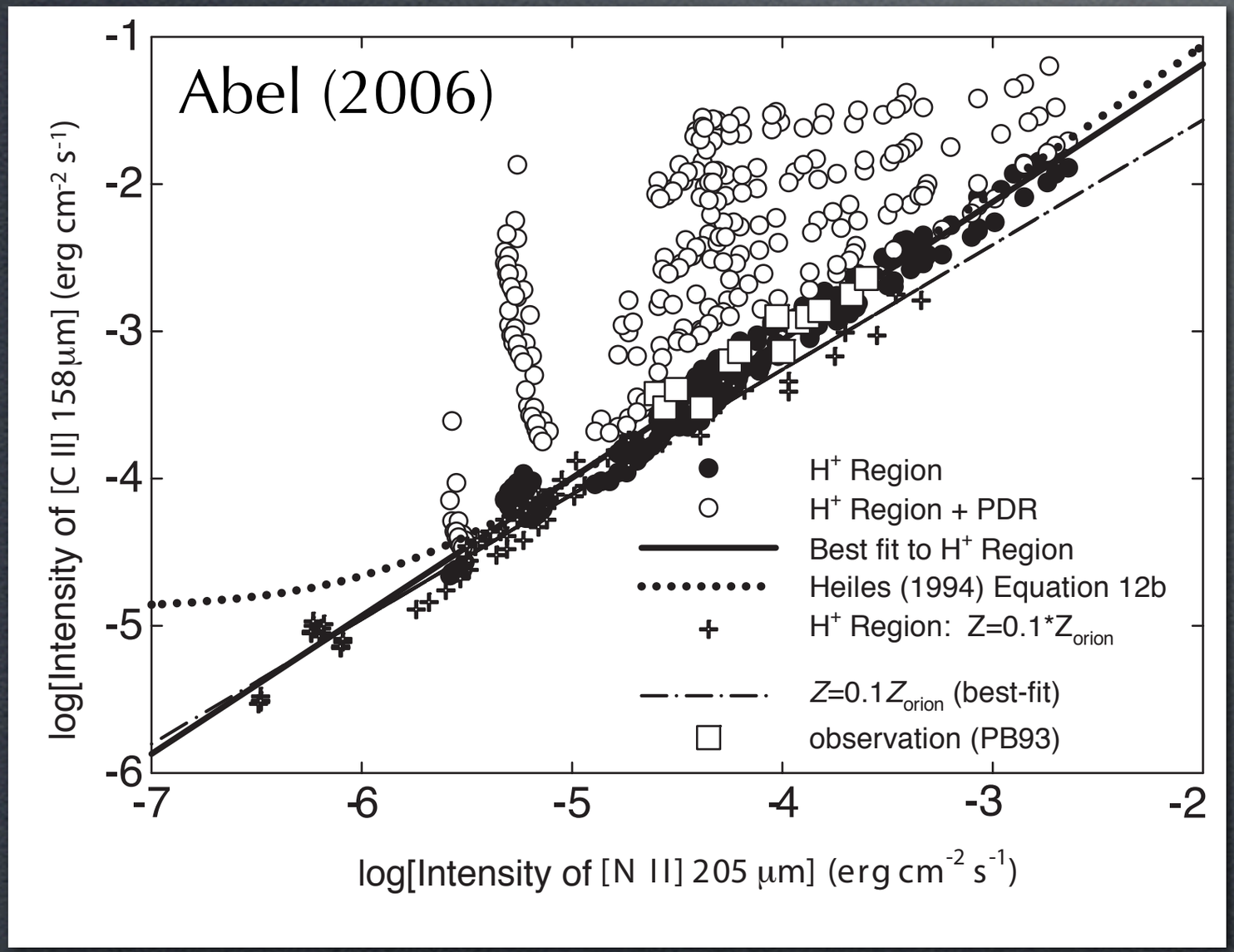


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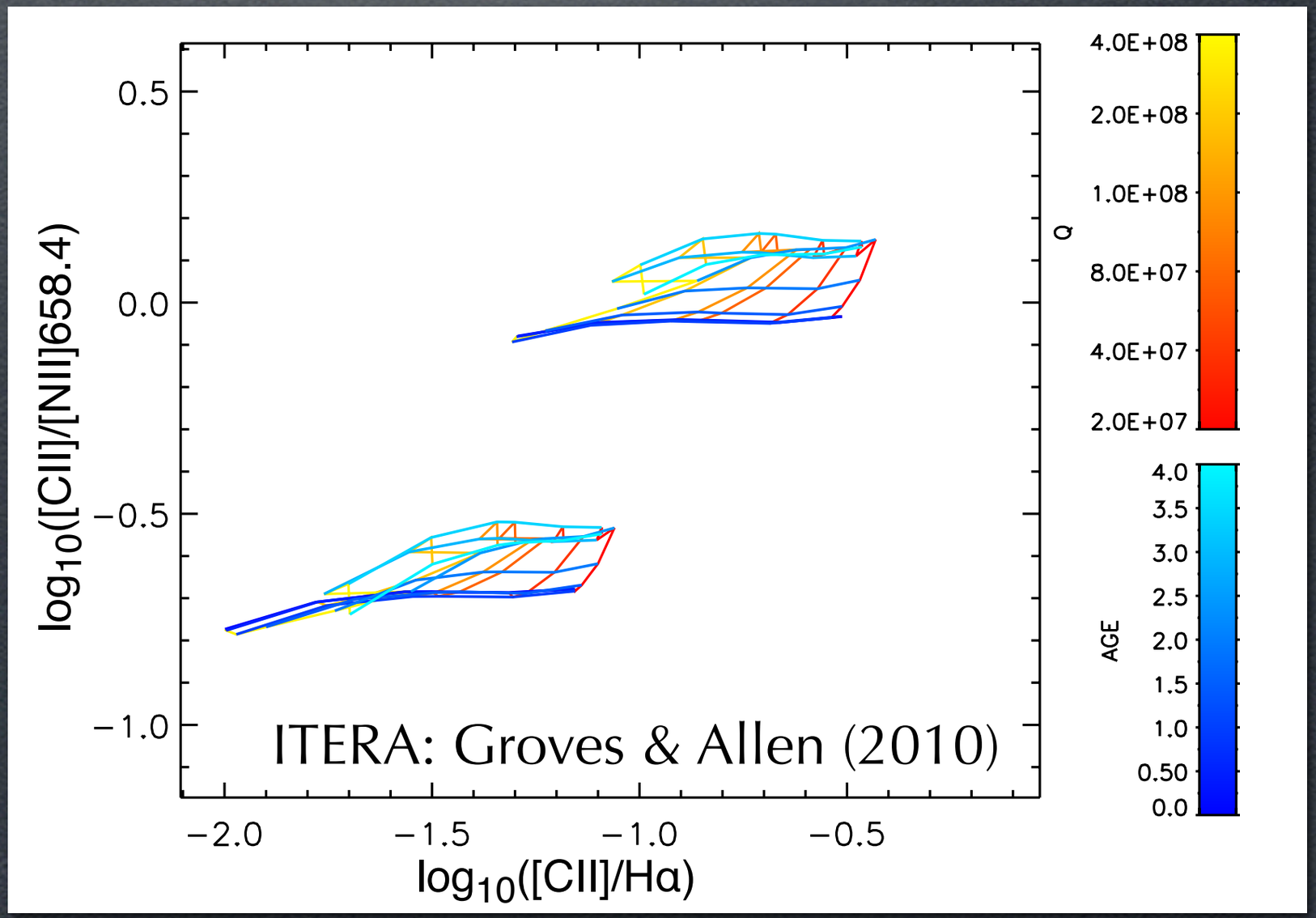
In all, 40-50% from (diffuse) ionised gas? (Heiles 94, PB93)

# No 205?

- Optical diffuse gas traces can be used: [NII] 658.4 nm, [SII] 681.7nm
- Even Hα is possible



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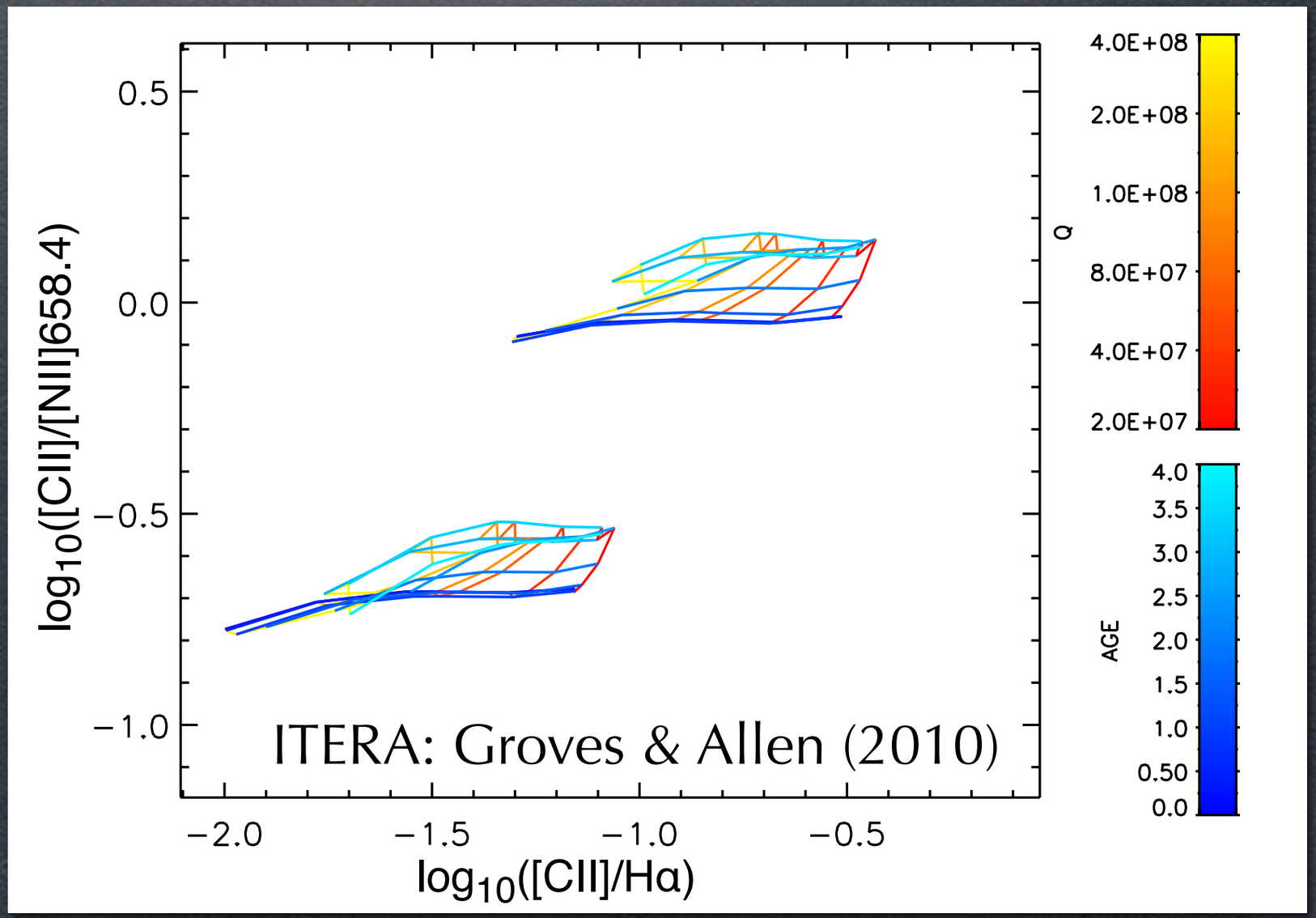
- Issues of Extinction & density

- Use radio free-free to measure $[CII]_{ion}$

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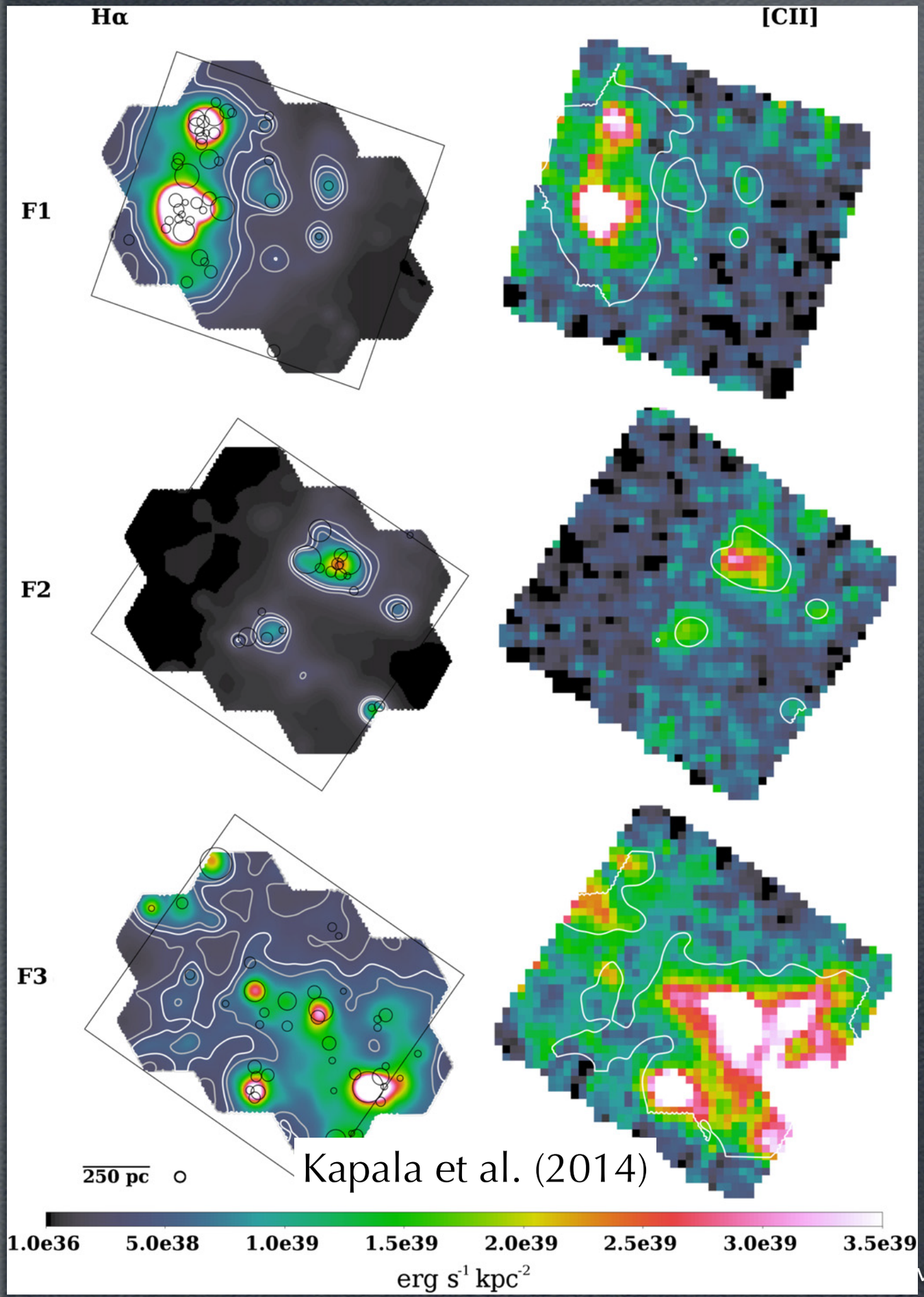
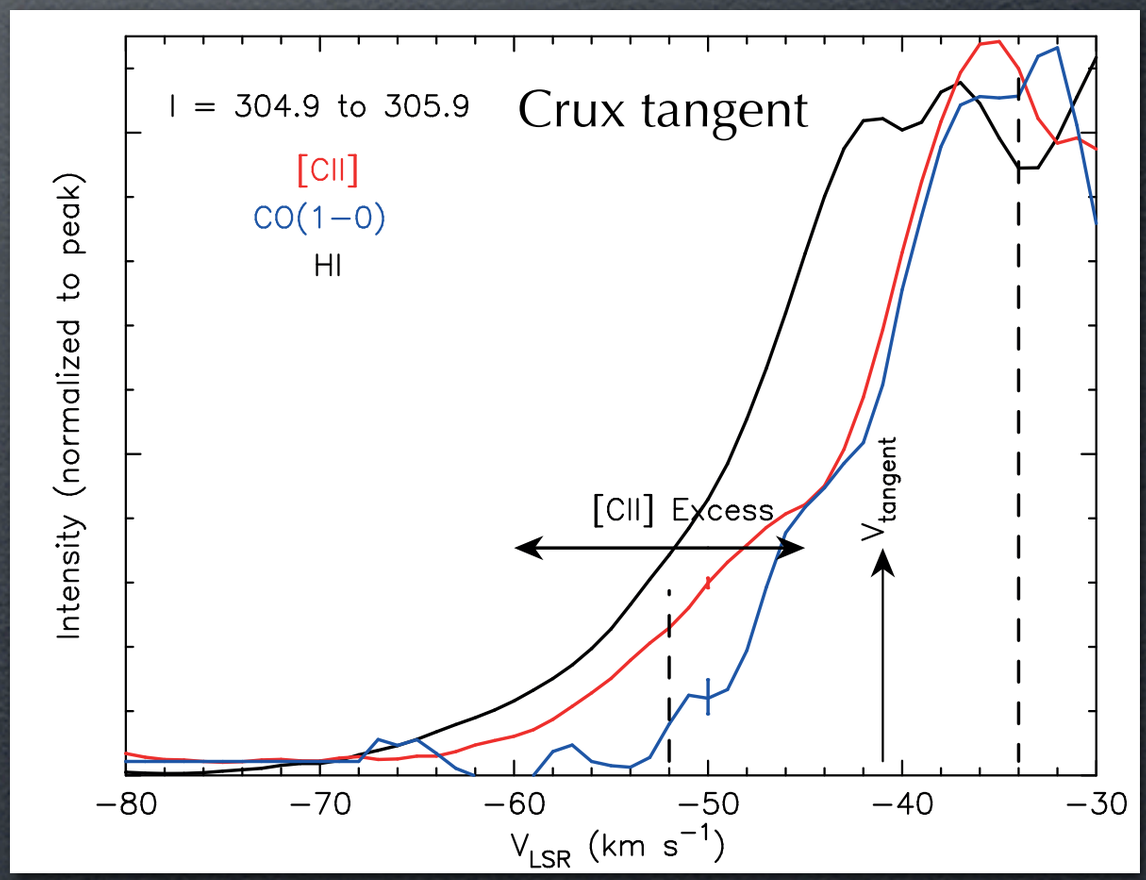
# Spatial & Spectral Separation

- Can associate [CII] with ionised and molecular components (M. Kapala's & J. Pineda's talk)




Kapala et al. (2014)




Velusamy et al. (2015)

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# AGN again?

- AGN provide strong X-ray fluxes
  - X-ray Dissociation Regions
  - eXtended ionised gas
  - Increased ionisation in WIM

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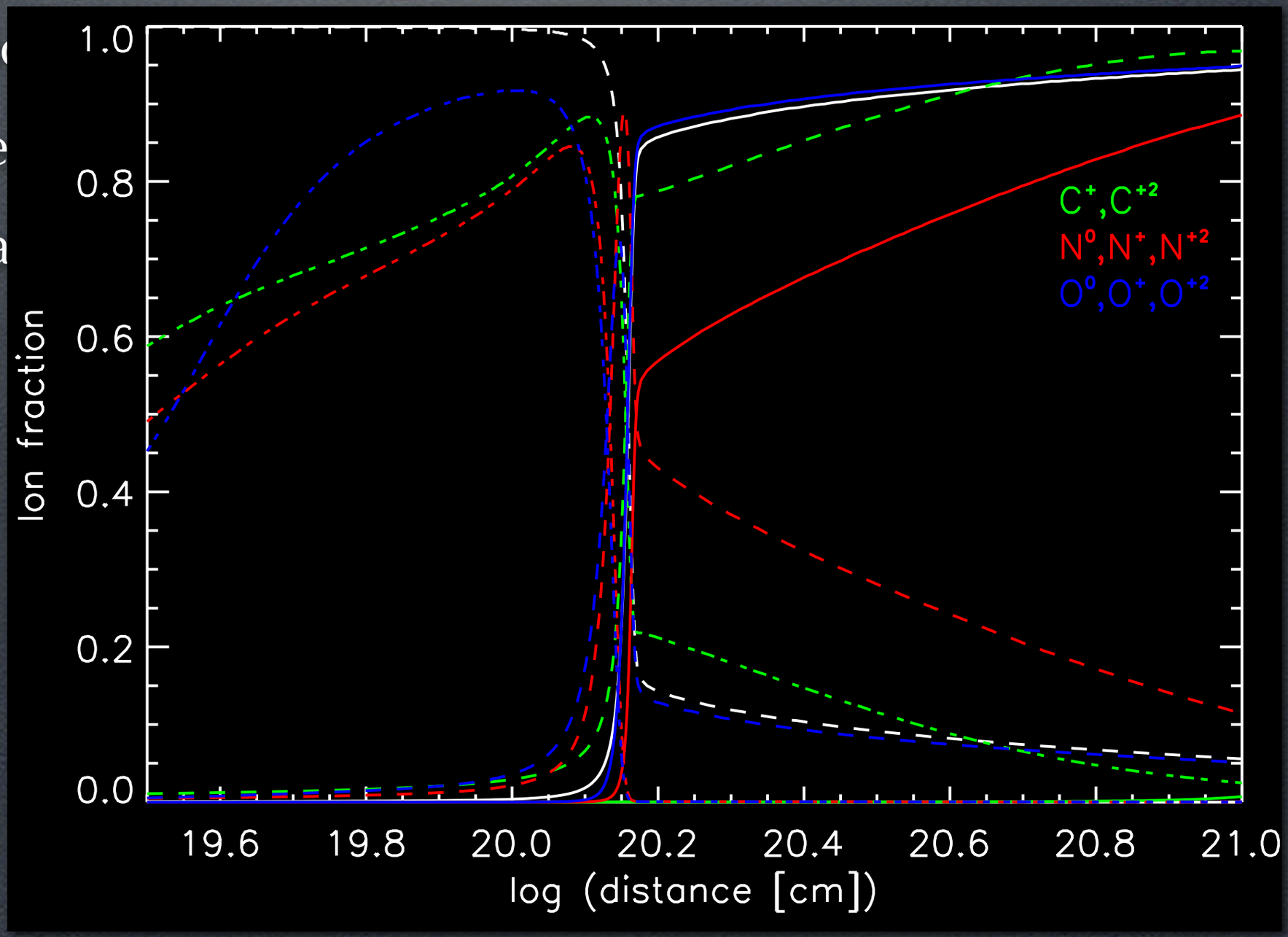

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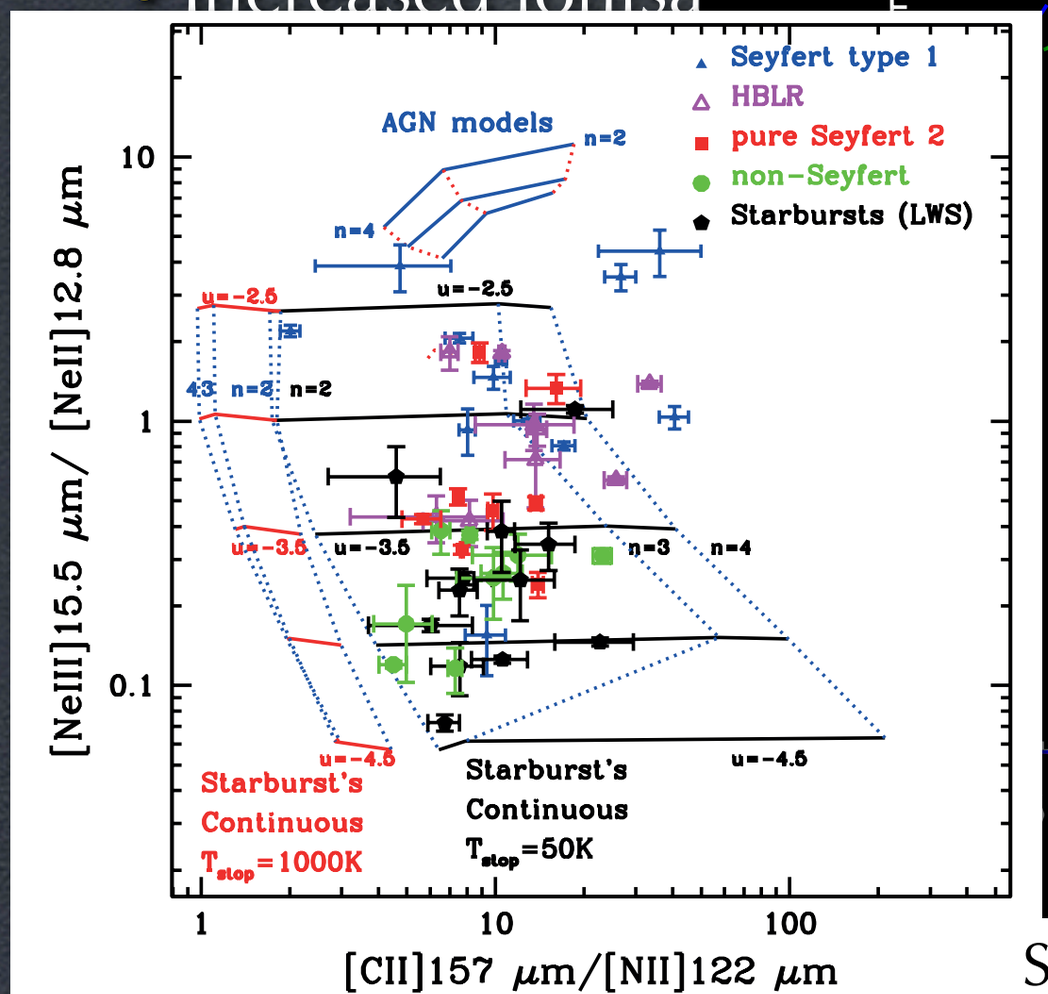
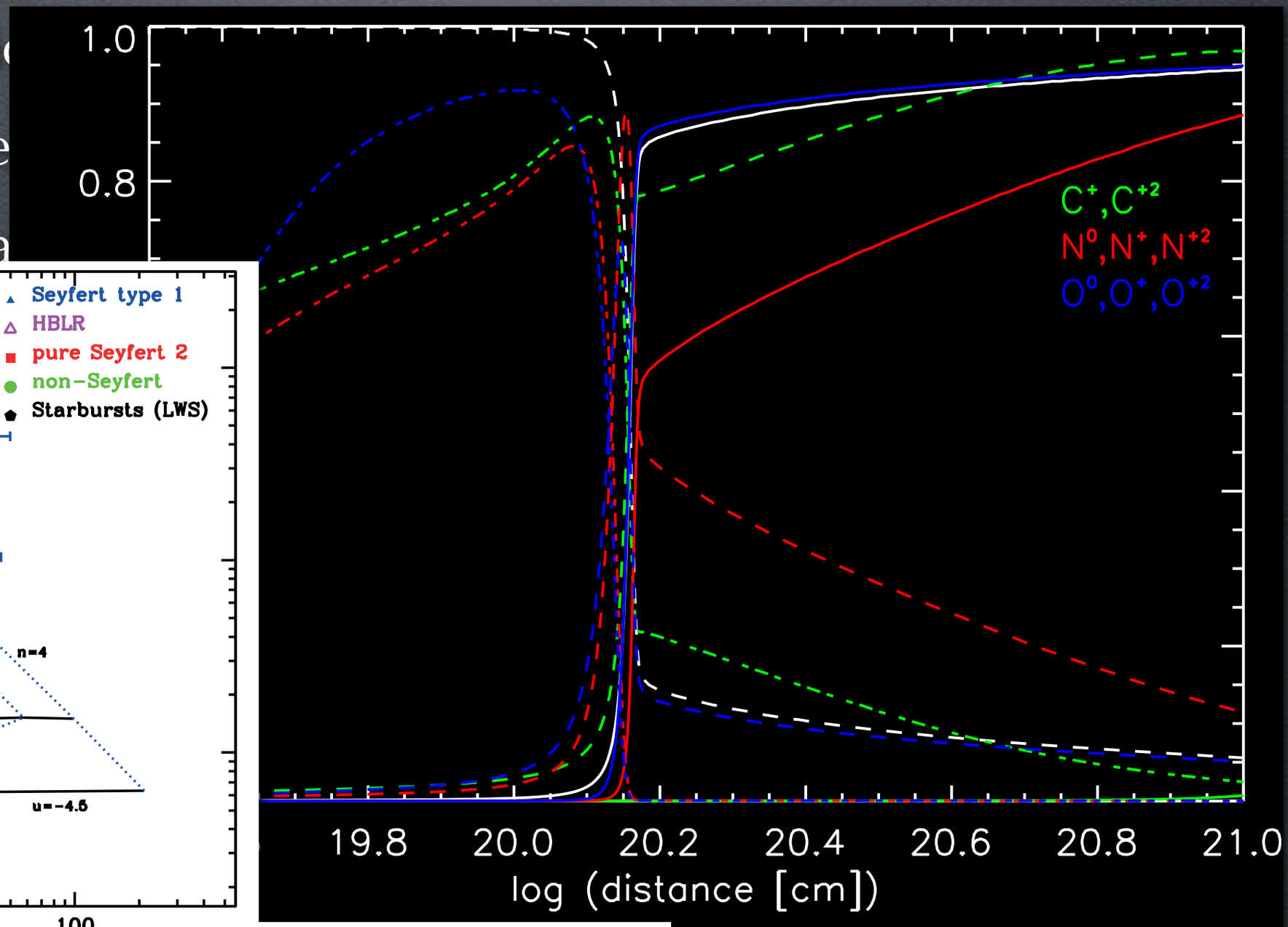
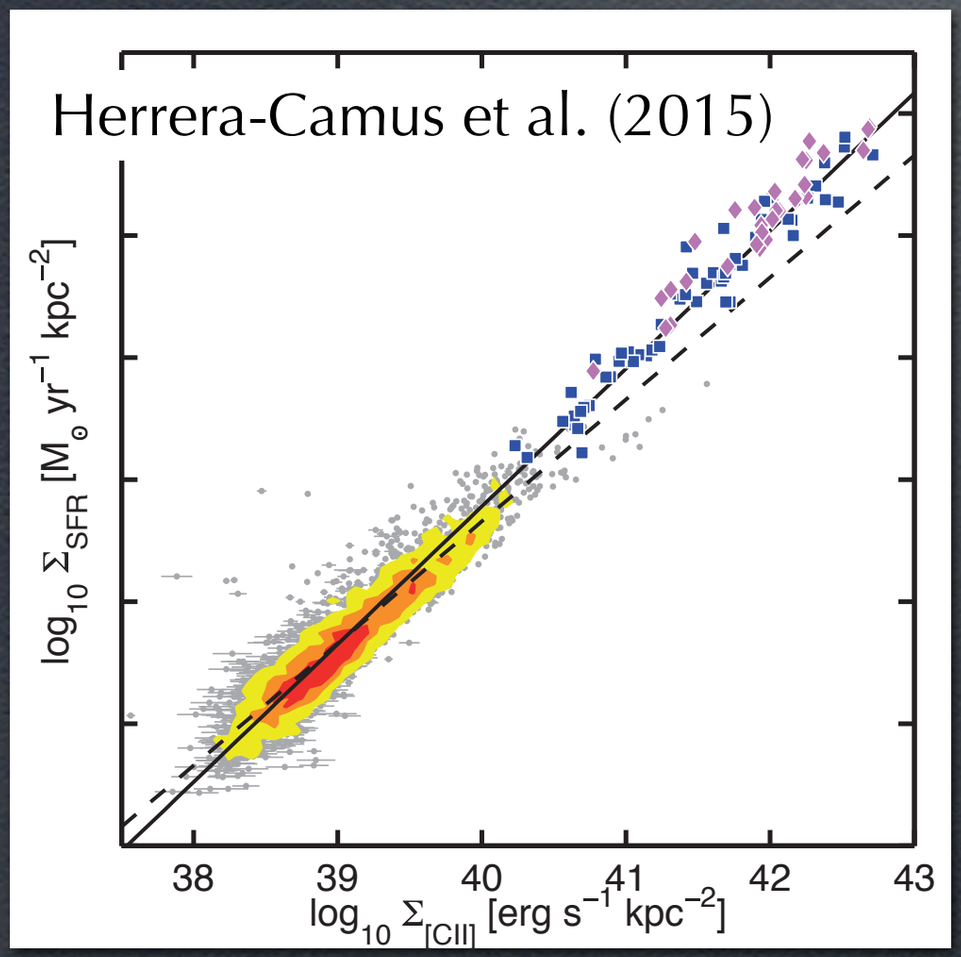



Spinoglio et al. (2015)

# Does Phase Matter?

- Phase doesn't seem to matter to [CII] as a SFR tracer
- Even at small scales!




- See Talks by: de Looze, Pineda, Kapala, …

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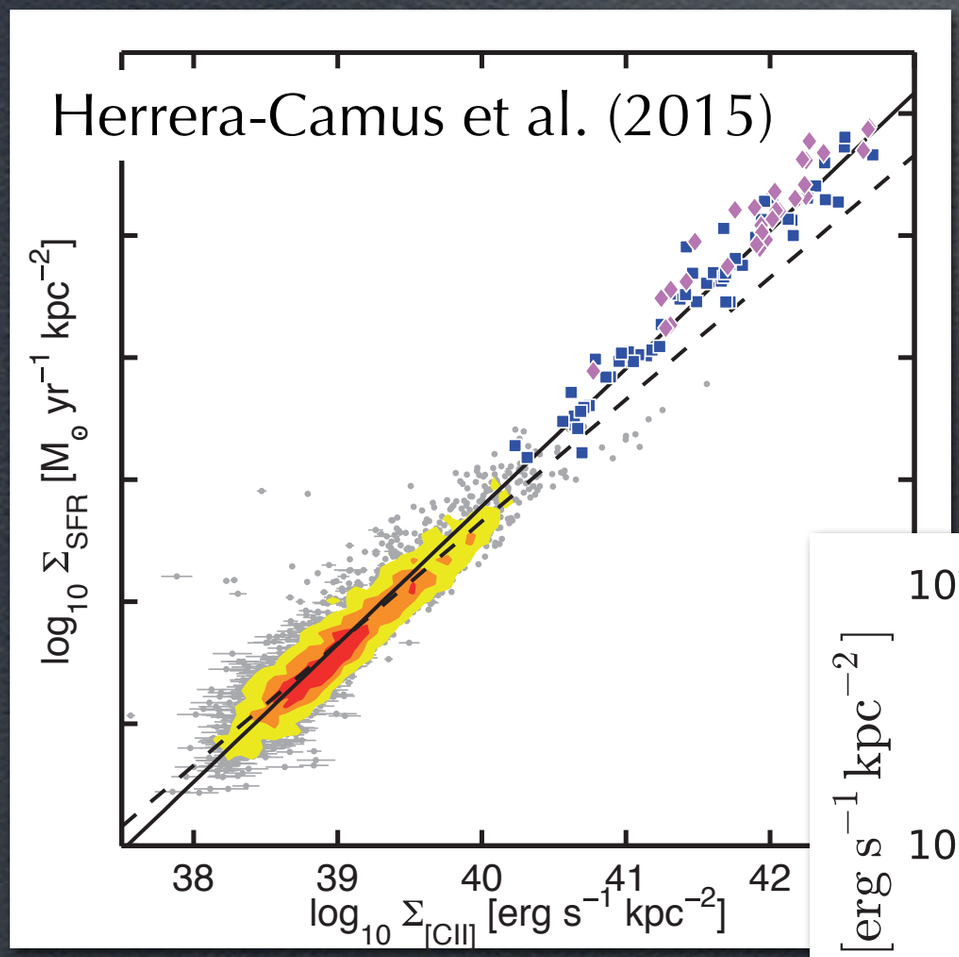


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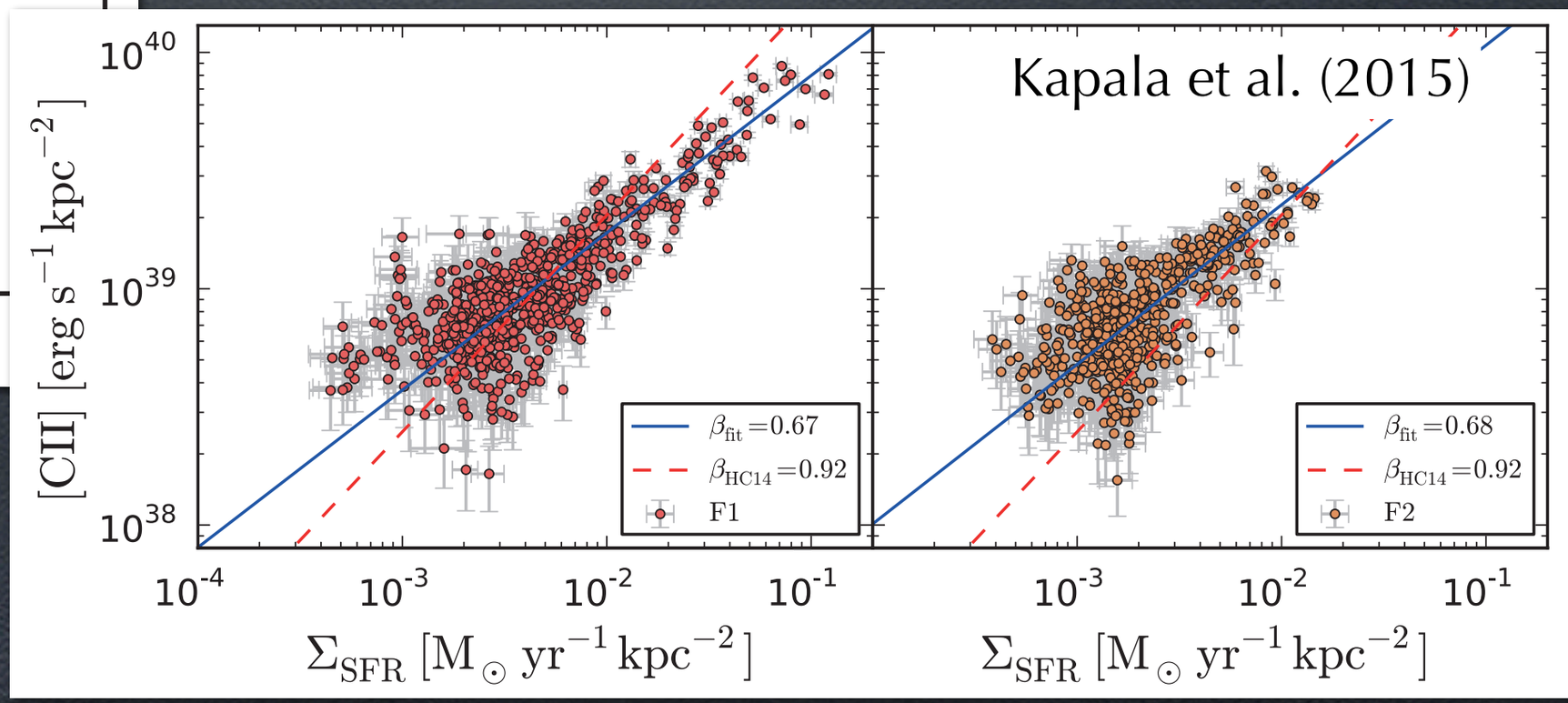
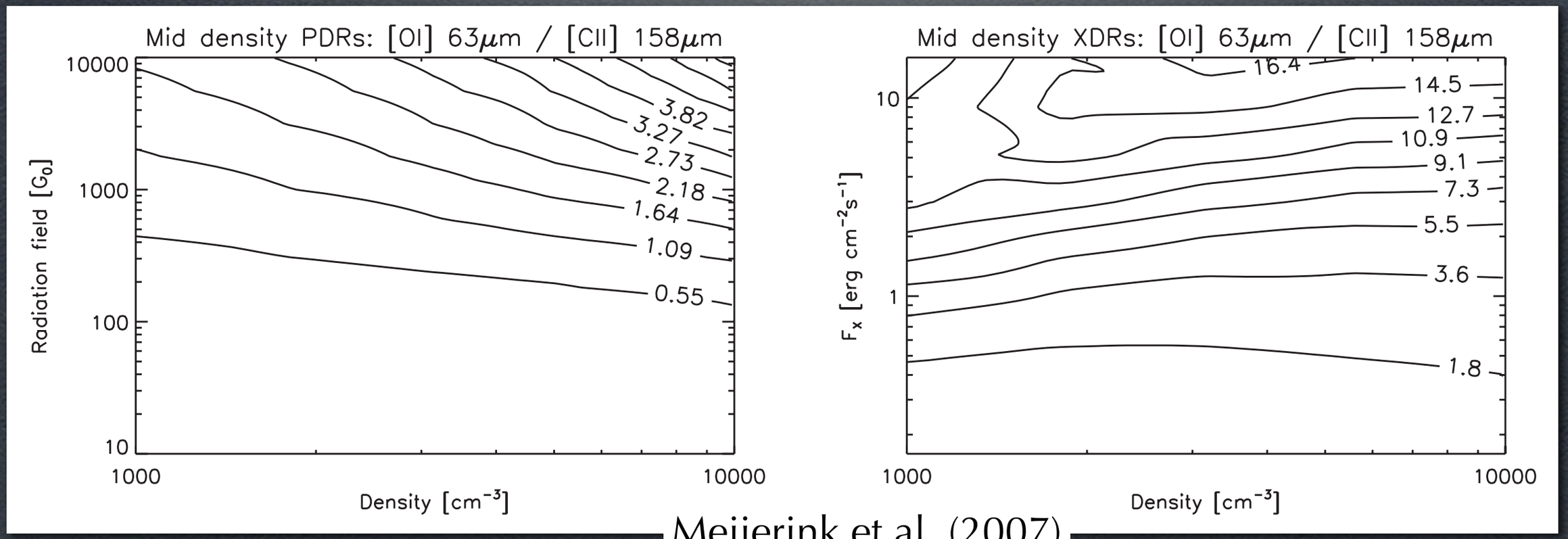


# Phased by gas diagnostics

- Phase separation needed for PDR/XDR diagnostics
- To understand neutral gas heating & photo-electric effect




Meijerink et al. (2007)

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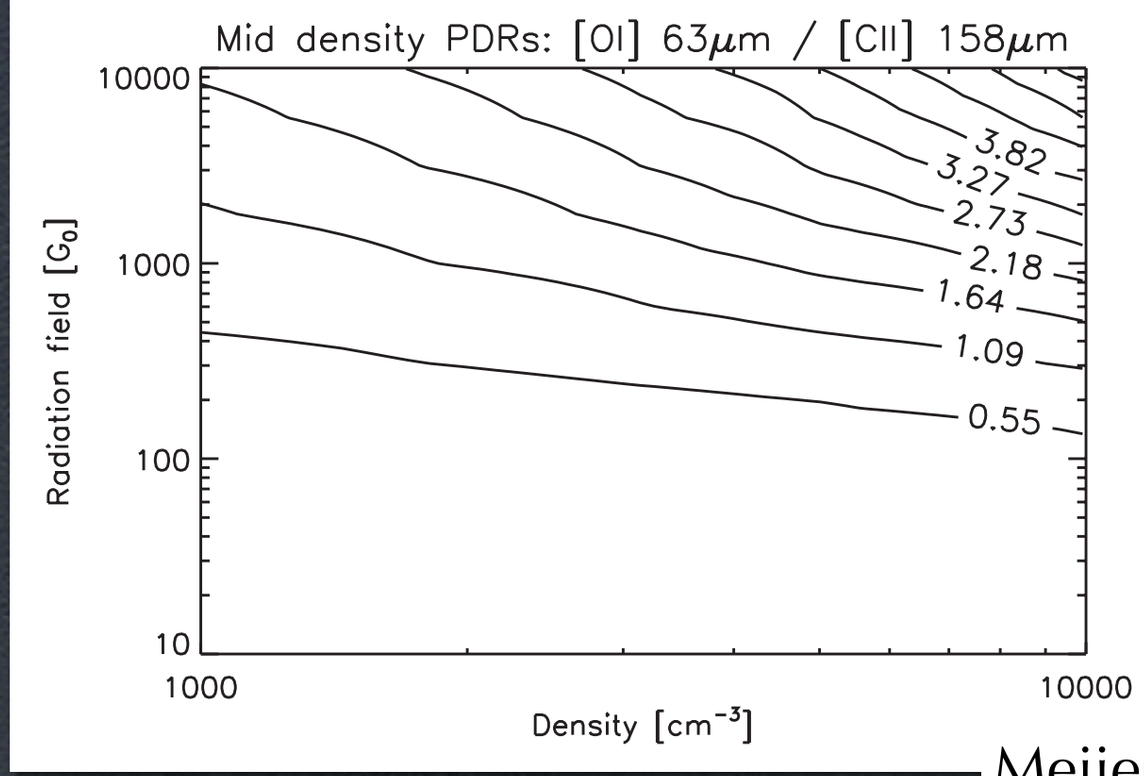


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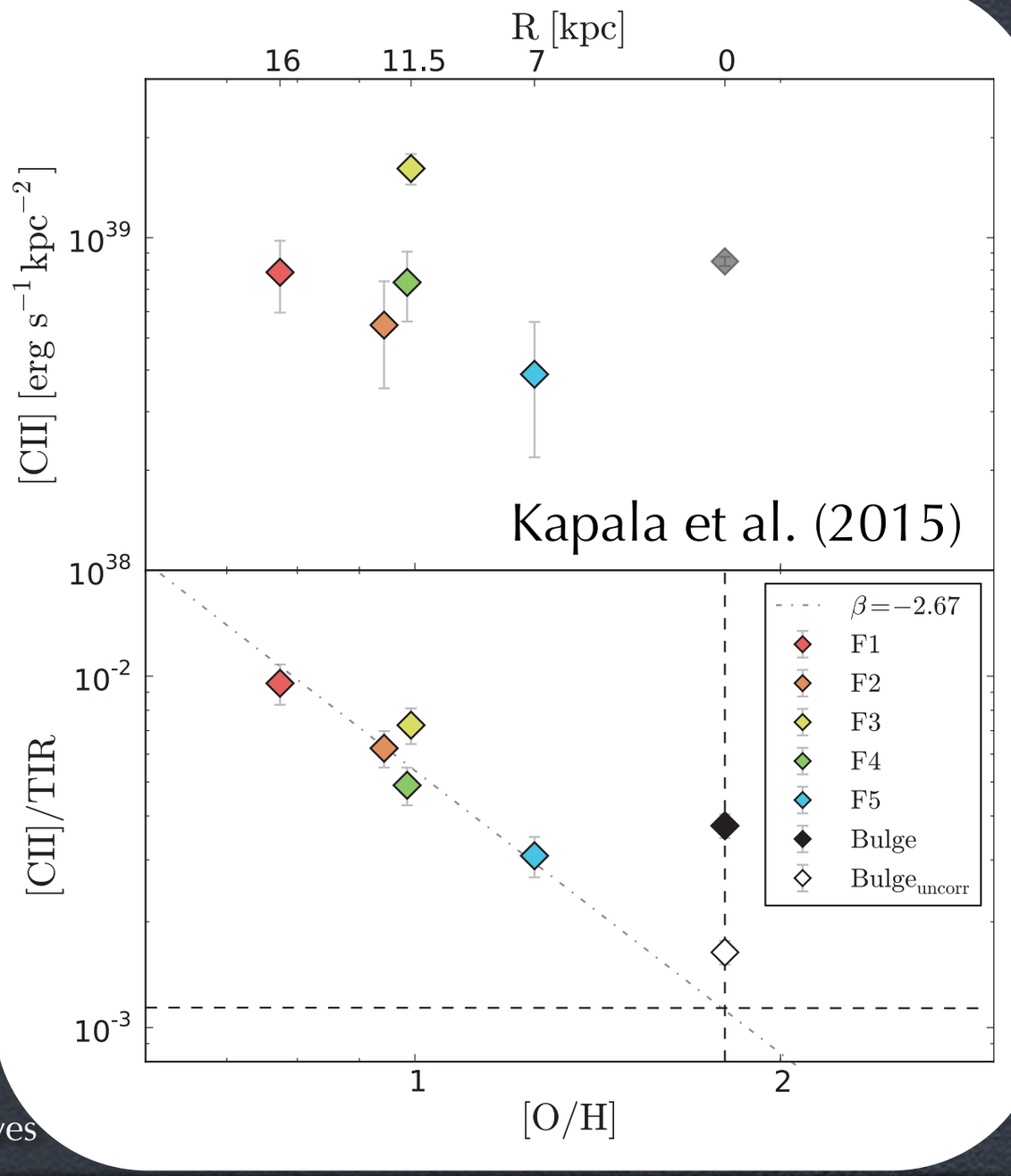


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# Multiphased Conclusion

- [CII] arises from multiple phases unlike other fine structure lines
- $[CII]_{ion}$ can be determined from [NII]205 to ~25%
  - but depends on metallicity
- $[CII]_{ion}$ can be determined from optical lines
  - but depends on metallicity, extinction, & excitation

- [CII] as a SFR tracer does not depend on separation
- [CII] as a diagnostic (in ionised or neutral medium) does